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COAL GASIFICATION STUDY AT CANMET's ENERGY RESEARCH LABORATORIES

D.P.C. Fung

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by

D.P.C. Fung*

ABSTRACT

This report summarizes the research on coal gasification at the Energy Research Laboratories from 1978 to 1983.

The chemical reactivity of 21 Canadian coals was compared in a laboratory fixed-bed gasifier. It was found that chemical reactivity increases with decreased carbon content (from 68 to 80 wt %) or rank of the coal. This range includes bituminous, subbituminous and lignite coals from five provinces. Above 80 wt %, the chemical reactivity levels off to 0.76 g/h/g. Similarly, the chemical reactivity also increases with the N_2 surface area of the coal at 0.85 m^2/g. The reactivity decreases significantly below this surface area.

Both oxygen and steam play an important role in coal gasification reaction. Oxygen speeds up the gasification reaction. Steam promotes the production of hydrogen according to the carbon-steam reaction.

The validity of the shrinking core model is verified with the carbon conversion data. It was found that coal gasification is a first order reaction. Wood gasification is a second order reaction.

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ÉTUDE DE LA GAZÉIFICATION DU CHARBON AUX LABORATOIRES DE RECHERCHE SUR L'ÉNERGIE DU CANMET

par

D.P.C. Fung*

RÉSUMÉ

Ce rapport présente un bref résumé des travaux de recherche sur la gazéification du charbon aux Laboratoires de recherche sur l'énergie de 1978 à 1983.

On a comparé la réactivité chimique de 21 charbons canadiens dans un gazéificateur à lit fixe de laboratoire. On a découvert que la réactivité chimique du charbon s'accroissait lorsque la teneur en carbone (de 68 à 80 % en poids) ou le rang des charbons diminuait. La gamme de charbons comprenait des charbons bitumineux, sub-bitumineux et des lignites en provenance de 5 provinces. Lorsque la teneur en carbone s'élevait au dessus de 80 % en poids la réactivité du charbon s'arrêtait au niveau de 0,76 g/h/g. On a aussi remarqué que la réactivité chimique s'accroissait de la même façon à la surface du charbon à 0,85 m^2/g déterminée par la méthode N_2 et que la réactivité diminuait considérablement au-dessous de cette surface.

L'oxygène et la vapeur jouaient tous les deux un rôle important au cours de la réaction de gazéification du charbon. L'oxygène accélérait la réaction de gazéification et la vapeur provoquait la production d'hydrogène selon la réaction carbone-vapeur.

On a de plus vérifié la validité du modèle servant à calculer l'ordre de la réaction à l'aide des données sur la conversion du charbon. On a découvert que la gazéification du charbon était une réaction de premier ordre et que la gazéification du bois était une réaction de second ordre.

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CONTENTS

	Page
ABSTRACT	i
RÉSUMÉ	ii
INTRODUCTION	1
EXPERIMENTAL	2
Gasification procedure	2
Materials	2
Gasification unit	2
Gas sampling and analysis	2
RESULTS AND DISCUSSION	3
Chemical Reactivity	3
Chemical Composition of Product Gas	5
Physical Properties	5
Reaction Kinetics	6
CONCLUSION	7
ACKNOWLEDGEMENTS	7
REFERENCES	8
APPENDICES	21

TABLES

No.		
1.	Chemical analysis of coal samples (moisture free)	9
2.	Carbon balance of 14 samples from gasification conditions A and B	10
3.	Chemical reactivity of coals under various gasification conditions	11
4.	Chemical composition of product gas (vol % N_2 free basis) at 800-860°C with O_2 and N_2	12
5.	Chemical composition of product gas (vol % N_2 free basis) at 800-840°C with O_2, air and steam	13

TABLES (Cont'd)

		Page
6.	Chemical composition of product gas (vol % N_2 free basis) at 950-1000°C with air and steam	14
A1.	Carbon conversion determined by weight and by product gas analysis under various gasification conditions at 30 min	21
A2.	Pore volume and N_2 surface area of nine coals	22

FIGURES

No.		
1.	ERL gasification unit	15
2.	Carbon conversion versus time under gasification condition A	16
3.	The relationship between chemical reactivity and carbon content of coal under gasification conditions A and B	17
4.	Relationship between N_2 surface area and carbon content of coal ...	18
5.	Correlation between chemical reactivity and surface area of coal o, No steam (condition A); Δ, steam gasification (B)	19
6.	Logarithmic plot of reaction time versus $[1-(1-X)^{1/3}]$ for testing shrinking core model with steam gasification	20

INTRODUCTION

Canada has abundant coal that can be readily gasified to produce a low to medium heating value gas for industrial use, or a synthesis gas for production of liquid fuels. Recent developments in gasification technology allow expanded uses for coal as a substitute for oil and natural gas. In 1977, CANMET's Energy Research Laboratories (ERL) initiated a coal gasification program aimed at stimulating industrial R & D in gasification and collecting reactivity data of potential Canadian coals for gasification application (1). This program was implemented by compiling data from outside research contracts by industry and research conducted in-house.

During the past five years, ERL's Gasification Section has acquired various equipment to study gasification of coal, pitch, oil shale and wood. Experimental facilities include a laboratory fluid-bed gasifier (batch, 200 g) laboratory fluid bed gasifier (continuous, 300 g/h) and high pressure (maximum 14 MPa) thermobalance reactor (batch, 5 g). This report summarizes a study from 1978 to 1983 using the laboratory fixed-bed gasifier. Studies concerning the fluid-bed gasifier and thermobalance reactor will be presented in a separate report.

Although Canada has enormous reserves of coal, little information is available in the literature on the reactivity of these coals in thermal conversion processes such as pyrolysis, liquefaction and combustion. Hence, there is an urgent need to develop this kind of information if more coal is to be utilized for oil substitution in Canada. Since 1977, a number of Canadian coals have been examined in the ERL's fixed-bed gasifier and results were reported previously (2,3,4,5,6). The gasifier has been designed so that the gasification reactivity of a coal sample can be screened within 30 min. This rapid screening method provides important reactivity data which can be used to establish a relationship between the chemical reactivity and the coal rank and determination of the kinetics of the gasification reaction. The ultimate goal is to derive a meaningful relationship between the results from the laboratory gasifier and those from the pilot plant gasifier.

This report presents experimental results from a study of 21 coals from five provinces. It provides a quick reference on the chemical reactivity and chemical composition of the product gas from coals of four ranks from different regions of Canada. A simple relationship between the chemical reactivity and the surface area of nine coals has been established.

EXPERIMENTAL

GASIFICATION PROCEDURE

Materials

The coals consisted of semi-anthracite, bituminous, subbituminous and lignite from British Columbia, Alberta, Saskatchewan, Ontario and Nova Scotia. The wood sample was spruce from Ontario. The particle size of the coal and wood samples ranged from 3 mm to 6 mm. The samples were air-dried, then oven-dried for 2 h at 105°C before using. Chemical analyses of the samples are reported in Table 1.

Gasification Unit

The gasification procedure was described in detail in a previous paper (2). Briefly, a 50-g coal sample was mixed with 25-g Berl saddles and was gasified in a cylindrical sample holder (4 cm diam x 30 cm long) which had a 6-mm diam opening for the incoming reacting gas mixture at the bottom of the holder. Figure 1 shows the position of the sample holder in the reactor tube.

Three reacting gas mixtures were used: condition A - equal mixture of nitrogen and oxygen, 1.8 L/min at 800-860°C; condition B - mixture of air, 1.5 L/min, oxygen, 0.5 L/min, and steam, 6 cm^3/min water rate at 800-840°C; and condition C - mixture of air, 2 L/min and steam, 3 cm^3/min water rate at 950-1000°C.

Duplicate experiments were performed on each sample with a gasification time of 30 min. The gasification residue in the reactor was cooled with a stream of nitrogen, 0.9 L/min, for 2 h before it was removed and weighed. Carbon balances were performed on 14 samples as shown in Table 2.

Gas sampling and analysis

A commercial Valco 16-port valve system was used for gas sampling and storage during the 30-min gasification. This system together with a gas chromatograph unit was described elsewhere (7). Fifteen samples were collected at 2-min intervals and analyzed individually at the end of the gasification.

A Perkin-Elmer Sigma 1 analyzer equipped with Porapak N and molecular sieve 5A columns were used for all the analyses. The carrier gas was a mixture of helium and hydrogen (8.5 vol %) at 45 cm^3/min. The column was programmed at 15°C/min from 40 to 75°C.

RESULTS AND DISCUSSION

Twenty-one coal samples were studied. Five were from British Columbia, 10 from Alberta, 3 from Saskatchewan, 1 from Ontario and 2 from Nova Scotia. Their carbon content on a dry ash-free basis (C^{daf}) varies from 92.6 wt % (semi-anthracite) to 67.9 wt % (lignite) and this variation provides a comfortable range for a comparative study of gasification reactivity of Canadian coals. Wood, which has a carbon content of 51.4 wt %, is used as a reference point at the limit of the chemical reactivity series.

In any chemical conversion process, three factors influence the chemical reactivity of coal - carbon content (or coal rank), surface area, and mineral content. The effects of carbon content and surface area are discussed in detail later. The effect of mineral content is considered significant when a large quantity of calcium oxide or magnesium oxide is present (5). The catalytic effect of these minerals will be discussed in a separate report.

Chemical Reactivity

Generally, the rate of reaction and chemical composition of the product gas depend on the coal reactivity and gasification conditions. Table 3 summarizes the chemical reactivities of 11 coals under gasification condition A, 21 coals under condition B and 9 coals under condition C. The chemical reactivity (rate of gasification) was calculated from the chemical composition of the coal and the product gas composition and volume. In each conversion curve, maximum reactivity occurs in the linear region as shown in Fig. 2 for those coals gasified under condition A. The reactivity can be calculated as follows:

$$R = \frac{1}{W}\frac{dc}{dt} \qquad \text{Eq 1}$$

where R is the maximum reactivity (g/h/g); W is the initial mass of coal (g) on an ash-free basis; and dc/dt is the slope of the linear region of the conversion curve (Fig. 2) and expressed as the weight loss rate (g/h).

Using Eq 1, the chemical reactivity of the high rank Alberta A semi-anthracite coal was determined as 0.74 g/h/g under condition A. The chemical reactivity for Ontario A (lignite) and for wood was 1.98 g/h/g and 4.68 g/h/g respectively under similar conditions.

Figure 3 depicts the general trend of the chemical reactivity with various coals under condition A (without steam) and condition B (with steam) at 800-840°C. The chemical reactivity is inversely proportional to the carbon content of the coal in the 68 to 80 wt % range under both conditions. Above 80 wt %, the chemical reactivity levels off to 0.76 g/h/g.

Since the oxygen feedrate in the gas mixture is about the same in both reaction systems (0.9 L/min in A and 0.8 L/min in B) the effect of steam on the 11 coals can be compared. It has been found that steam has little effect on Alberta A and B (bituminous) coals under these two conditions (3). The steam lowers the reactivity of British Columbia C, Nova Scotia A, Saskatchewan A and B but increases the reactivity of Alberta I and Ontario A.

For the nine coals and wood gasified at 950-1000°C in the presence of steam and air (condition C) the chemical reactivities of Alberta A and B, British Columbia B are lower, but of Alberta D, Nova Scotia B and Ontario A, are higher than those obtained with a surplus of oxygen at 800-840°C (Table 3). There is only a slight increase in the chemical reactivity of Nova Scotia A, Saskatchewan A and B coals. Generally, the chemical reactivity increases with decreased carbon content of coal.

It has been found that Alberta E and F are most reactive among the ten bituminous coals studied. Carbon conversion for these two coals is high and they are considered good gasification feedstock. On the other hand, the eastern bituminous coal, Nova Scotia B, is a less suitable feedstock because it is less reactive and contains 4.9 wt % sulphur.

Alberta I is the most reactive subbituminous coal with highest carbon conversion when compared with the other five subbituminous coals under condition B (Table 3). It should be a good gasification feedstock in the subbituminous rank.

Among the four lignites, Ontario A is most reactive with highest carbon conversion. However, its 5.4 wt % sulphur renders it less attractive as a gasification feedstock when compared with the western lignites.

It must be noted that the highest carbon conversion obtained from this study was 81 wt % by gas analysis as shown in Fig. 2. Once a maximum conversion is reached at a certain gasification temperature, the conversion curve tends to level off. A 100% conversion is unattainable due to the chemical composition (ash content) of the coal, and its physical behaviour (agglomeration) under heat treatment.

Additional information on carbon conversion and physical properties of the coals is given in Appendix 1 and 2.

Chemical Composition of Product Gas

Tables 4, 5 and 6 summarize the results of the chemical composition of the coals studied under gasification conditions A, B, and C. The chemical composition of the product gas at the 10-min gasification interval was sampled and analyzed by gas chromatograph (Tables 4,5,6).

At 800-860°C in the absence of steam, the production of hydrogen decreases, but that of carbon monoxide increases, with decreased carbon content of coal (Table 4). This trend is reversed when steam is used (Table 5). The increase of hydrogen with increased carbon content is expected because the carbon monoxide formed will be converted into hydrogen and carbon dioxide according to the water-gas shift reaction. The large quantity of methane production (22.2 vol %) from British Columbia A bituminous coal is surprising (Table 5) and one may explain that methane is product from the pyrolysis process because the gasification reactivity of this coal is low at 800-860°C. Since methane formation from the carbon-steam reaction at atmospheric pressure is not thermodynamically favourable, its formation is independent of the carbon content.

The production of hydrogen is from 43 to 54 vol % from the gasification of 9 coals at 950-1000°C with air and steam (Table 6). The production of carbon monoxide varies from 16 to 25 vol %. The carbon content appears to have only a small effect on the chemical composition of the product gas with feedrates of air and steam at 2 L/min and 3 cm^3/min (water rate) respectively at 950-1000°C.

Physical Properties

The physical properties of 11 coals were studied and their effects on the chemical reactivity of coal were reported (5).

Figure 4 shows a correlation between the N_2 surface area and the carbon content of 9 coals. It has been found that the Ontario A lignite has a surface area of 3.76 m^2/g compared with 0.76 m^2/g of the high rank Alberta A semi-anthracite. The surface area curve declines from 3.76 m^2/g (Ontario A) as the carbon content increases until it levels off for coals with carbon content higher than 80 wt %.

Figure 5 shows that the coal reactivity decreases with decreased surface area which reflects primarily the size and volume of the micropores in coals. In the region of 0.85 m^2/g corresponding to 80 wt % carbon content the reactivity drops drastically, signifying that the small surface area is no longer a controlling factor (Fig. 4). In addition to surface area, the total pore volume, micropore volume and the apparent compressibility also decrease with increased carbon content (5).

Reaction Kinetics

When the rates of diffusion through fluid-film and porous solid are both very fast, the overall rate of a solid-fluid reaction is solely controlled by inherent chemical reactivity of the solid reactant (8). It has been found that the coal-steam and coal-oxygen reactions (9,10) are well represented by the shrinking-core model, consequently, this model has been used to interpret the present experimental results (8).

In the shrinking core model, where chemical reaction is the rate-controlling step, the following equation can be applied for the determination of the order of the reaction (8,10):

$$t/t^* = 1 - (1-X)^{1/3} \qquad \text{Eq 2}$$

where t is the reaction time, X the carbon conversion fraction (obtained directly from Fig. 2) and t^* the time for complete conversion. Hence, a slope of unity from a plot of log t versus log [1-(1-X)] from Eq 2 indicates that chemical reaction is the rate-controlling step. A slope of 2 indicates that ash-diffusion is the rate-controlling step (8).

Figure 6 shows typical plots of the carbon conversion data versus the time, t, for Nova Scotia B, Alberta D, Saskatchewan A and B and Ontario A. The data show the coal gasification reaction is controlled by the first-order chemical reaction as the slopes of the lines obtained in the plot are very close to unity. When the shrinking core model is used for determining the order of the wood gasification reaction, a slope of 2 is obtained (not shown in Fig. 6). This shows that ash-diffusion is the rate-controlling step in wood gasification reaction providing that this model is also applicable to wood.

CONCLUSIONS

The chemical reactivity of 21 Canadian coals can be meaningfully compared in a laboratory fixed-bed gasifier. In general, the chemical reactivity increases with decreased carbon content (68 to 80 wt %) or rank of the coal. This range includes bituminous, subbituminous and lignite coals from five provinces. Above 80 wt %, the chemical reactivity levels off to 0.76 g/h/g.

Similarly, the chemical reactivity also increases with the N_2 surface area of the coal to a surface area of 0.85 m^2/g. The reactivity decreases significantly below this surface area.

Both oxygen and steam play an important role in coal gasification reaction - oxygen speeds up the reaction and steam promotes the production of hydrogen according to the carbon-steam reaction.

The validity of the shrinking core model is verified with the carbon conversion data. It has been found that coal gasification is a first order reaction. Wood gasification is a second order reaction.

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Table 1 - Chemical analysis of coal samples (moisture free)

Sample	Proximate analysis (wt %)			Ultimate analysis (wt %)				
	Ash	Volatile matter	Fixed[a] carbon	C	H	S	N	O[a]
Alberta A	15.1	11.9	73.0	78.6	3.6	0.8	1.5	0.4
Alberta B	8.2	18.1	73.7	83.1	4.3	0.6	1.2	2.6
British Columbia A	9.4	21.3	69.3	80.8	4.1	0.3	1.0	4.4
Alberta C	11.0	25.3	63.7	78.5	4.2	0.3	1.3	4.5
British Columbia B	14.4	22.2	63.4	75.6	4.2	0.4	1.2	4.2
British Columbia C	15.3	26.2	58.5	74.4	4.3	0.8	1.2	4.0
Nova Scotia A	2.9	35.4	61.7	84.7	5.6	1.3	1.3	4.2
British Columbia D	8.4	25.7	65.9	79.0	4.4	0.6	1.6	6.0
Alberta D	9.5	37.1	53.4	71.9	4.7	0.2	1.1	12.6
Nova Scotia B	15.6	43.6	49.8	66.0	4.5	4.9	1.4	7.6
Alberta E	12.1	40.4	47.5	68.3	4.6	0.6	1.9	12.5
Saskatchewan A	12.5	41.4	46.1	66.1	2.2	0.6	1.3	17.3
Alberta F	13.5	40.3	46.2	65.0	3.8	0.8	1.5	15.4
Alberta G	13.4	36.4	50.2	65.0	4.4	0.6	1.4	15.2
British Columbia E	27.5	34.2	38.3	53.6	3.6	0.4	1.1	13.8
Alberta H	6.9	40.4	52.7	67.6	4.1	0.6	1.4	19.4
Alberta I	22.1	33.6	44.3	56.3	3.2	0.3	0.7	17.4
Saskatchewan B	13.4	43.5	43.1	61.1	3.6	1.1	1.0	19.8
Alberta J	24.4	40.9	34.7	52.8	3.8	0.4	1.3	17.3
Saskatchewan C	18.5	41.4	40.1	55.8	3.9	1.5	1.1	19.2
Ontario A	26.8	40.0	33.2	49.7	3.3	5.4	0.7	14.1
Wood	1.7	76.4	21.9	50.5	5.3	0	0.1	42.4

[a]Determined by difference.

Table 2 - Carbon balance of 14 samples from gasification conditions A and B

Sample	C in sample (g)	C in tar[a]	C in solid particulate	C in residue	C in gas	C in product / C in sample x 100%
Gasification product (g) from condition A						
British Columbia C	37.4	4.7	0.4	11.9	16.4	89
Nova Scotia A	42.6	4.6	0.2	16.9	16.0	88
Nova Scotia B	33.1	4.9	0.2	11.8	14.4	95
Saskatchewan A	33.6	7.4	0.3	0	22.7	91
Saskatchewan B	30.8	5.3	0.2	0	22.7	92
Gasification product (g) from condition B						
Alberta A	39.6	3.8	0.1	18.1	14.3	92
Alberta B	42.1	2.9	0.1	18.9	15.4	89
Nova Scotia A	42.6	4.6	1.5	19.7	15.0	96
British Columbia C	38.4	4.7	1.0	14.2	13.6	87
Nova Scotia B	33.3	4.9	1.4	15.0	10.5	95
Alberta D	36.2	4.8	1.7	11.6	14.3	90
Saskatchewan A	33.3	7.4	1.8	0.6	21.0	93
Saskatchewan B	31.1	5.3	3.1	0.2	21.4	97
Ontario A	25.3	1.8	0.2	0.1	18.8	83

[a]The amount of tar was found in respective gasification experiments without steam and used here. This tar was estimated to contain 80 wt % carbon for the calculation.

Table 3 - Chemical reactivity of coals under various gasification conditions

Sample (Rank)	C^{daf}, wt %	Maximum reactivity, g/h/g		
		A	B	C
Alberta A semi-anthracite	92.6	0.74	0.76	0.36
Alberta B bituminous	90.5	0.75	0.77	0.50
British Columbia A bituminous	88.3	-	0.81	-
Alberta C bituminous	88.2	-	0.91	-
British Columbia B bituminous	88.0	-	0.81	-
British Columbia C bituminous	87.8	0.99	0.76	0.60
Nova Scotia A bituminous	87.2	0.93	0.78	0.75
British Columbia D bituminous	86.2	-	0.76	-
Alberta D subbituminous	79.5	1.08	0.84	0.90
Nova Scotia B bituminous	78.1	1.08	0.78	0.85
Alberta E bituminous	77.6	-	1.14	-
Saskatchewan A lignite	75.5	1.84	1.44	1.45
Alberta F bituminous	75.1	-	1.44	-
Alberta G subbituminous	75.0	-	1.68	-
British Columbia E subbituminous	74.0	-	1.50	-
Alberta H subbituminous	72.6	1.80	1.56	-
Alberta I subbituminous	72.3	1.74	1.83	-
Saskatchewan B lignite	70.6	1.86	1.71	1.75
Alberta J subbituminous	69.8	-	1.71	-
Saskatchewan C lignite	68.4	-	1.92	-
Ontario A lignite	67.9	1.98	2.17	2.30
Wood	51.4	4.68	-	4.11

Gasification condition:

A - 0.9 L/min N_2; 0.9 L/min O_2; 800-860°C.

B - 1.5 L/min air; 0.5 L/min O_2; 6.0 cm^3/min steam; 800-840°C.

C - 2.0 L/min air; 3.0 cm^3/min steam; 950-1000°C.

Table 4 - Chemical composition of product gas (vol % N_2 free basis) at 800-860°C with O_2 and N_2

Sample	H_2	O_2	CH_4	CO_2	CO
Alberta A	24.9	0	11.7	46.5	16.9
Alberta B	26.1	0	8.3	48.6	17.0
British Columbia C	20.4	0.5	2.6	56.1	20.4
Nova Scotia A	30.2	0.4	9.5	42.0	17.9
Alberta D	24.4	0	12.5	35.6	27.5
Nova Scotia B	13.7	0	14.4	58.4	13.5
Saskatchewan A	11.6	0.7	0.3	27.5	59.9
Alberta H	20.8	0	3.2	24.2	51.8
Alberta I	17.2	0	3.3	28.6	50.9
Saskatchewan B	17.1	0	1.3	26.7	54.9
Ontario A	11.6	1.9	0.3	23.1	63.1
Wood	15.6	0	3.5	31.7	49.2

Table 5 - Chemical composition of product gas (vol % N_2 free basis) at 800-840°C with O_2, air and steam

Sample	H_2	O_2	CH_4	CO_2	CO
Alberta A	32.0	1.5	0.4	35.7	30.4
Alberta B	31.7	1.5	1.8	37.2	27.8
British Columbia A	27.0	0.8	22.2	36.8	13.2
Alberta C	36.7	0.8	11.1	25.8	25.6
British Columbia B	31.0	1.0	14.5	23.8	29.7
British Columbia C	29.6	1.8	3.7	50.0	14.8
Nova Scotia A	37.4	1.6	5.1	39.0	17.0
British Columbia D	37.4	0.8	13.1	26.5	22.2
Alberta D	48.2	0.8	3.1	32.5	15.4
Nova Scotia B	29.2	2.0	6.2	43.8	18.8
Alberta E	54.1	0.2	5.1	25.3	15.3
Saskatchewan A	57.4	0.5	1.3	24.2	16.6
Alberta F	23.5	0	12.7	33.0	30.8
Alberta G	52.7	0.5	2.0	26.8	18.0
British Columbia E	62.3	0	2.0	22.2	13.5
Alberta H	59.4	0	1.1	21.9	17.6
Alberta I	59.1	0	1.3	24.5	15.1
Saskatchewan B	51.3	1.2	1.3	32.9	13.3
Alberta J	61.3	0	1.7	23.8	13.2
Saskatchewan C	58.9	0	1.6	22.4	17.3
Ontario A	57.3	0.5	1.3	24.4	16.5

Table 6 - Chemical composition of product gas (vol % N_2 free basis) at 950-1000°C with air and steam

Sample	H_2	O_2	CH_4	CO_2	CO
Alberta A	54.2	2.0	7.0	15.8	21.0
Alberta B	43.8	1.6	13.5	16.3	24.8
British Columbia C	45.4	2.0	7.5	22.2	23.0
Nova Scotia A	43.4	1.1	16.6	13.2	25.7
Alberta D	54.1	0.7	6.0	23.2	16.0
Nova Scotia B	45.8	1.5	12.9	20.4	19.3
Saskatchewan A	50.6	0.7	5.6	24.3	18.8
Saskatchewan B	53.9	0.6	2.2	22.7	20.6
Ontario A	48.9	0.6	1.9	23.8	24.8
Wood	48.8	0.9	1.6	25.6	23.1

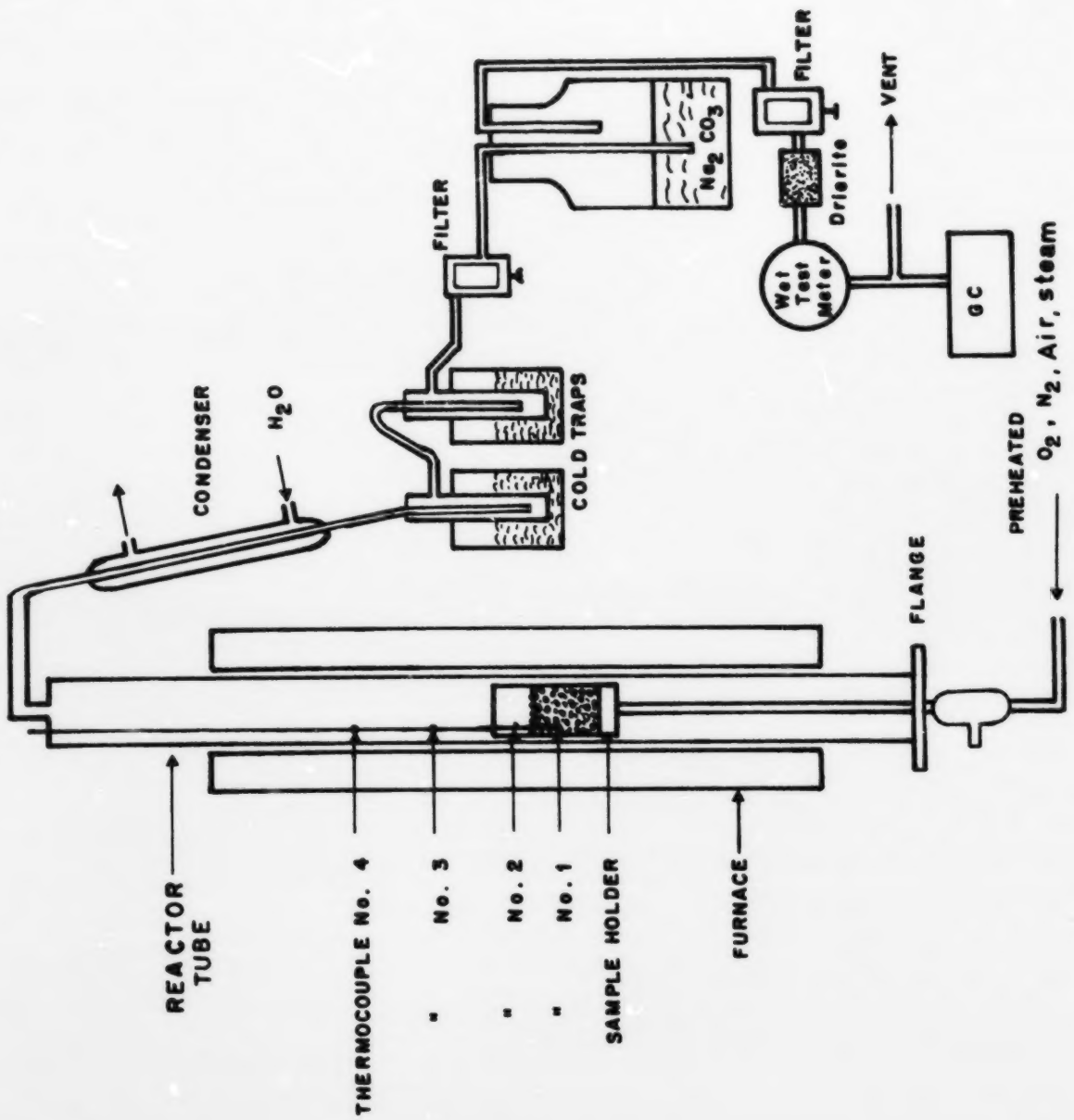

Fig. 1 - ERL gasification unit

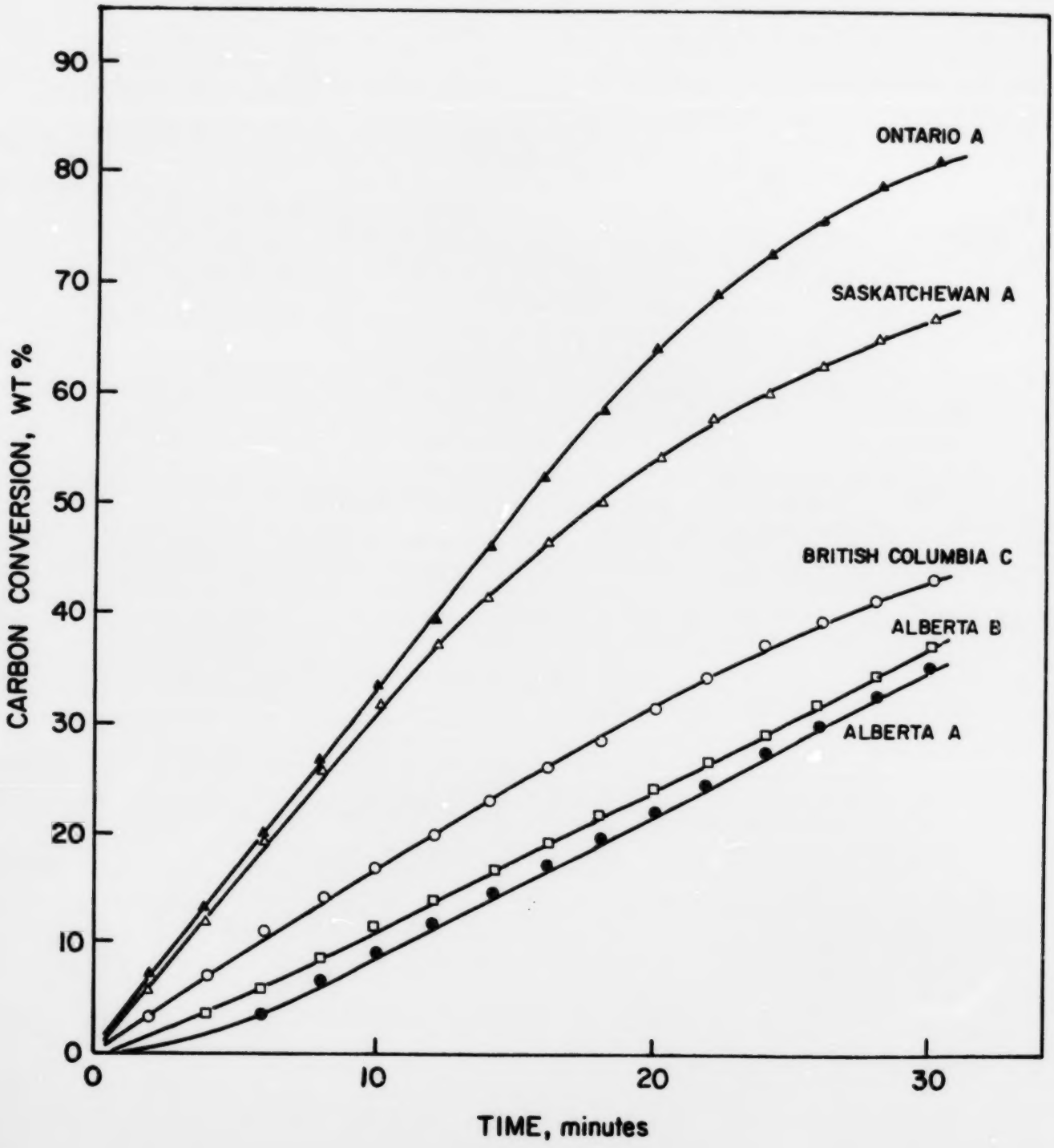

Fig. 2 - Carbon conversion versus time under gasification condition A

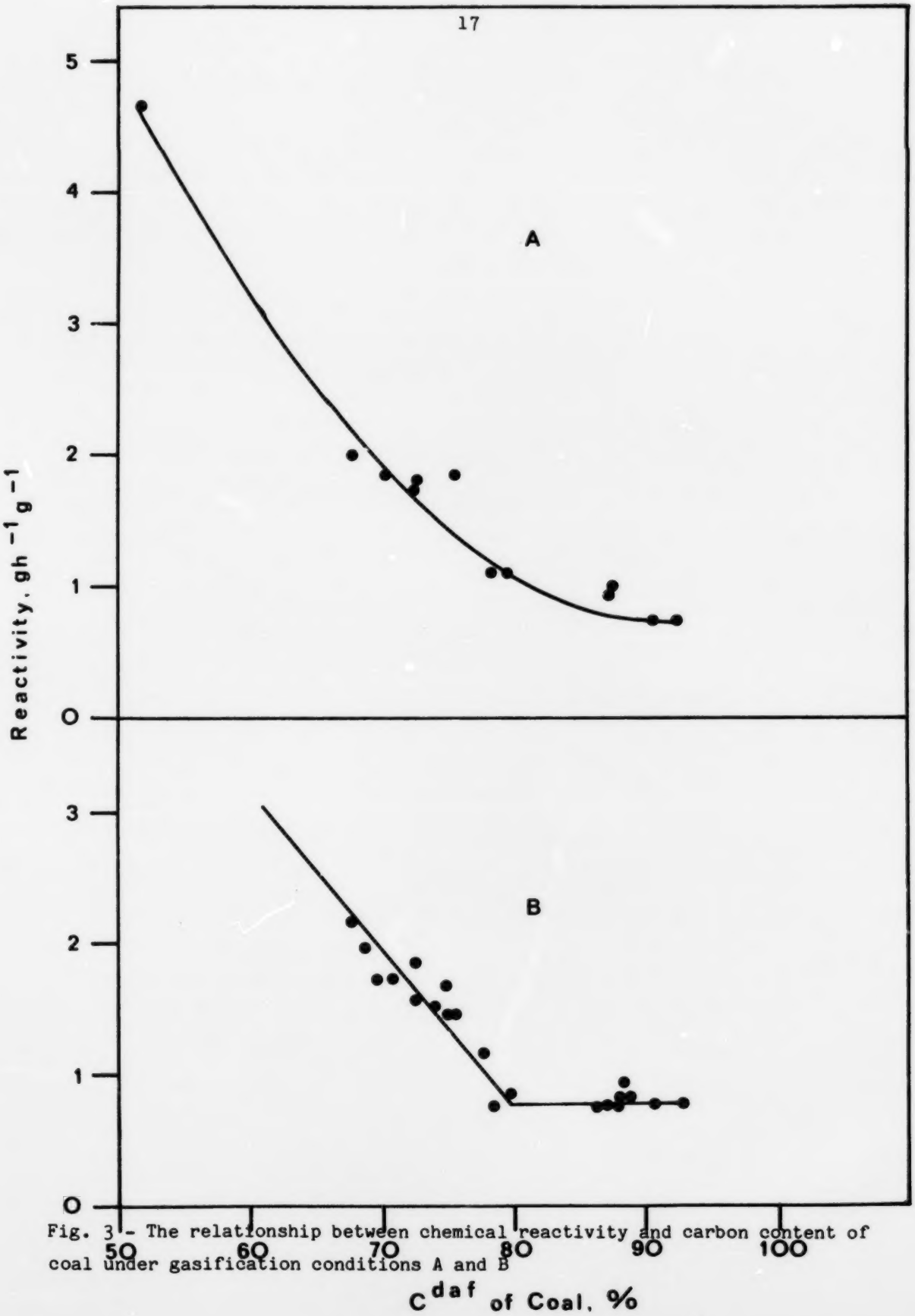

Fig. 3 - The relationship between chemical reactivity and carbon content of coal under gasification conditions A and B

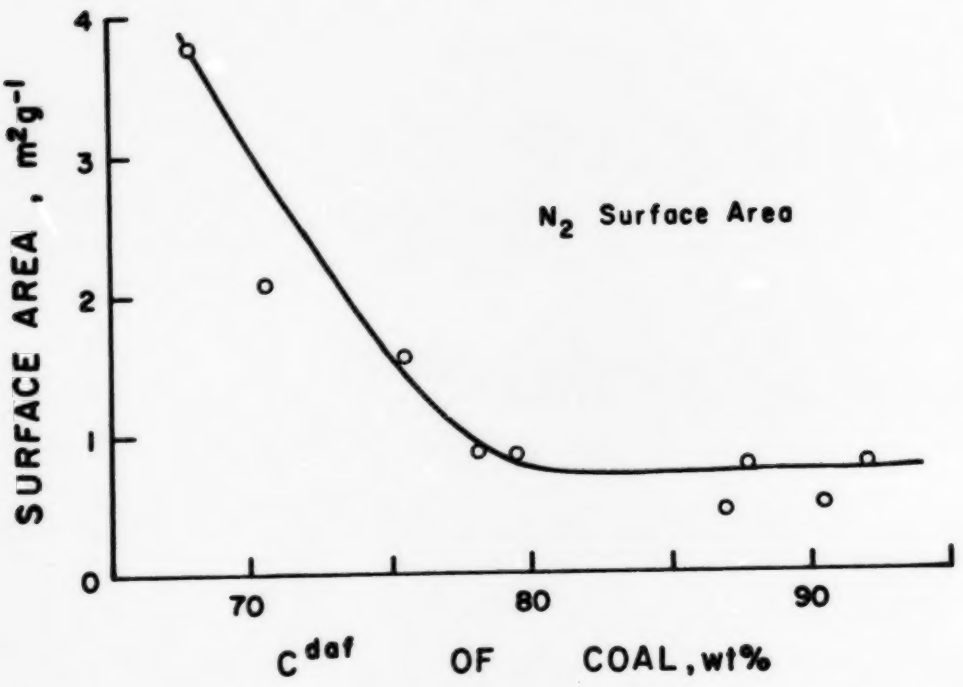

Fig. 4 - Relationship between N_2 surface area and carbon content of coal

Fig. 4 - Relationship between N_2 surface area and carbon content of coal

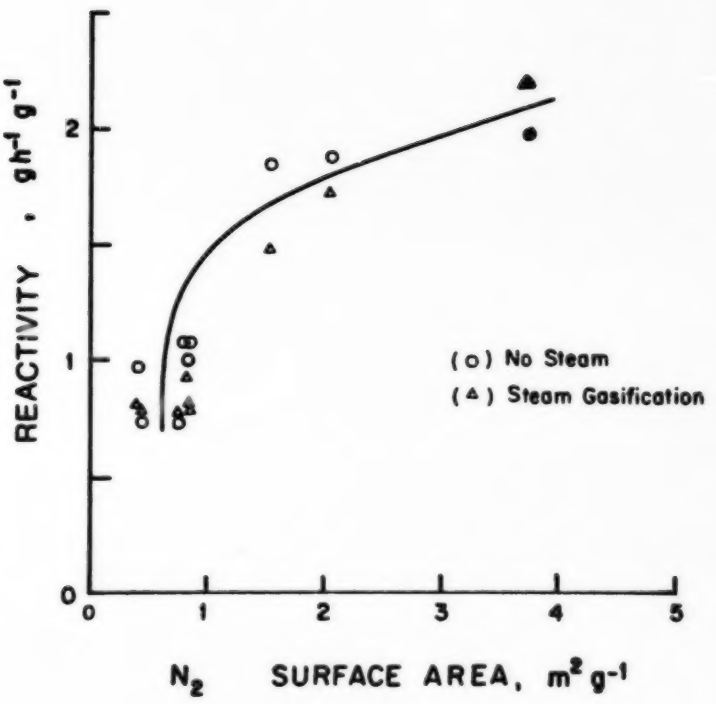

Fig. 5 – Correlation between ~~gasification~~ chemical reactivity and surface area of coal. O, No steam (Condition A); Δ, steam (Condition B) gasification

Fig. 5 - Correlation between chemical reactivity and surface area of coal. o, No steam (condition A); Δ, steam gasification (condition B)

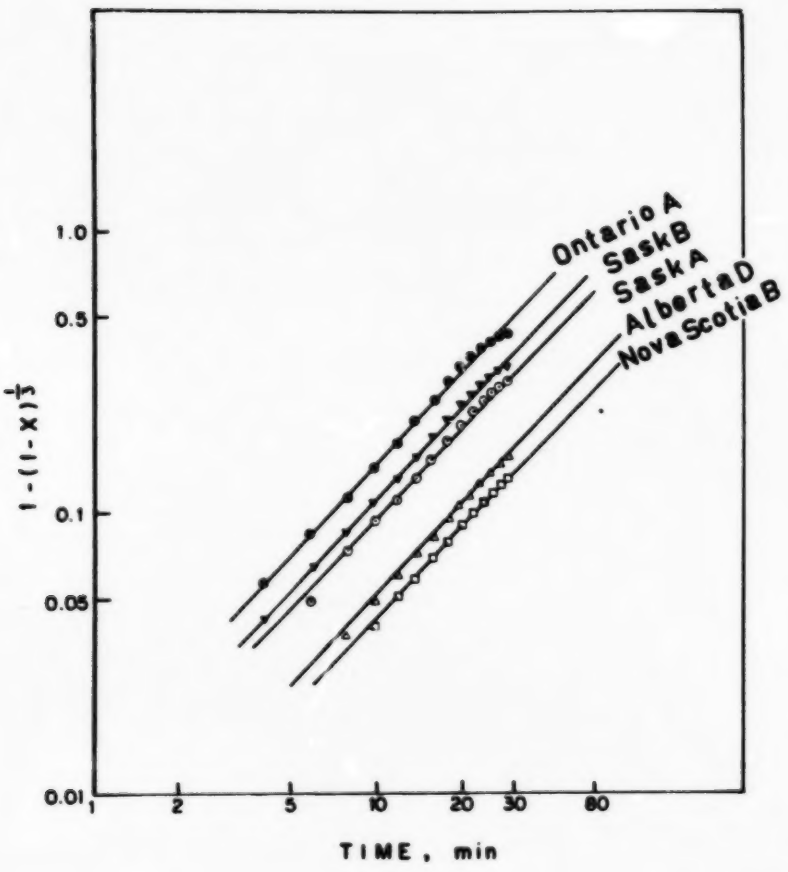

Fig. 6 - Logarithmic plot of reaction time versus $[1-(1-x^{1/3}]$ for testing shrinking core model with steam gasification

Fig. 6 - Logarithmic plot of reaction time versus $[1-(1-X)^{1/3}]$ for testing shrinking core model with steam gasification

APPENDIX 1

Table A1 - Carbon conversion determined by weight and by product gas analysis under various gasification conditions at 30 min

	Gasification condition					
	A		B		C	
Sample	by wt	by gas	by wt	by gas	by wt	by gas
Alberta A	ND	35	44	36	ND	23
Alberta B	ND	37	48	37		
British Columbia A			ND	35		
Alberta C			ND	35		
British Columbia B			ND	38		
British Columbia C	54	44	47	35		
Nova Scotia A	49	37	39	35	ND	30
British Columbia D			ND	36		
Alberta D			50	39	ND	47
Nova Scotia B	49	44	36	31	ND	38
Alberta E			ND	56		
Saskatchewan A	77	67	71	63	ND	66
Alberta F			ND	62		
Alberta G			ND	54		
British Columbia E			ND	70		
Alberta H			ND	62		
Alberta I	ND	72	ND	67		
Saskatchewan B	82	74	72	69	ND	60
Alberta J			ND	67		
Saskatchewan C			ND	73		
Ontario A	ND	81	92	74	ND	76
Wood	ND	81			ND	78

ND - Not determined.

APPENDIX 2

Table A2 - Pore volume and N_2 surface area of nine coals

Sample	Total pore volume ($ml g^{-1}$) [macro+meso+micropore]	N_2 surface area ($m^2 g^{-1}$)
Alberta A	0.042	0.76
Alberta B	0.018	0.48
British Columbia C	0.074	0.86
Nova Scotia A	0.020	0.43
Alberta D	0.051	0.84
Nova Scotia B	0.064	0.86
Saskatchewan A	0.093	1.56
Saskatchewan B	0.116	2.09
Ontario A	0.384	3.76